EFFECT OF TAPER ANGLE ON PROCESSING LOAD IN FORWARD EXTRUSION

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Abstract. There is actuality that forward extrusion processing is difficult when taper angle of die is less than 2°. Aim of this study is to reveal the reason why the forward extrusion processing is difficult in the case of 2°. To know the reason, we simulated forming processes with two-dimensional axisymmetric models under the same processing conditions. Each of two-dimensional axisymmetric model has different taper angles. Processing conditions are same reduction rate in area and taper angles from 25° to 2°. As a result, the smaller the taper angle, the bigger the processing load. To investigate the reason, we compared with contact pressure distributions in these angles. And then, it was revealed that the smaller the taper angle, the bigger the contact pressure distribution at the upper of taper section. When the contact pressure is large, it seems that friction force and the processing load become big. From the above, in the case of 2°, processing load is large. Therefore, depending on the machine, it is difficult to process the blank.

1 INTRODUCTION

In production site, there is actuality that forward extrusion processing is difficult when taper angle of die is less than 2°. In the forward extrusion, engineers have decided the taper angle of die along their experiences. Aim of this study is to reveal the reason why the forward extrusion processing is difficult in the case of 2°. To know the reason, we simulated forming processes with two-dimensional axisymmetric models under the same processing conditions. Each of two-dimensional axisymmetric model has different taper angles. Processing conditions are same reduction rate in area and taper angles from 25° to 2°. In this paper, the formability of forward extrusion is investigated by deformation pattern, contact pressure, load value, plastic strain and strain rate.

2 ANALYSIS PROCEDURE AND METHOD

We used Simufact forming 13.0 (MSC Software Corporation) for analysis and made two-dimensional axisymmetric models of die with the taper angle of 2°,4°, 6°, 8°, 10°, 15°, 20° and 25°. Figure 1 shows two-dimensional axisymmetric models of die we made. Extrusion die used in this work having reduction factor of 10:5 (Inlet diameter: Outlet diameter).Therefore, reduction rate in area is 0.25. The work piece data used S45C with the dimension of 10mm, 60mm and 80mm in length and 10mm diameter. In the case of 2°, work piece length is 80mm, because amount of work piece for filling the tapered portion is insufficient. For perform analysis under the same conditions, in the case of 6° and 15°, work piece length is 80mm. In the case of less than 10°, work piece length is 60mm. On the other hand, In the case of more than 20°, work piece length is 10mm. Material property in database of Simufact formig was used for workpiece. Punch speed is 200mm/s. To observe the effect of friction, coulomb friction and shear friction are 0.1 and 0.3. From the above conditions, we performed analysis and investigated formability.

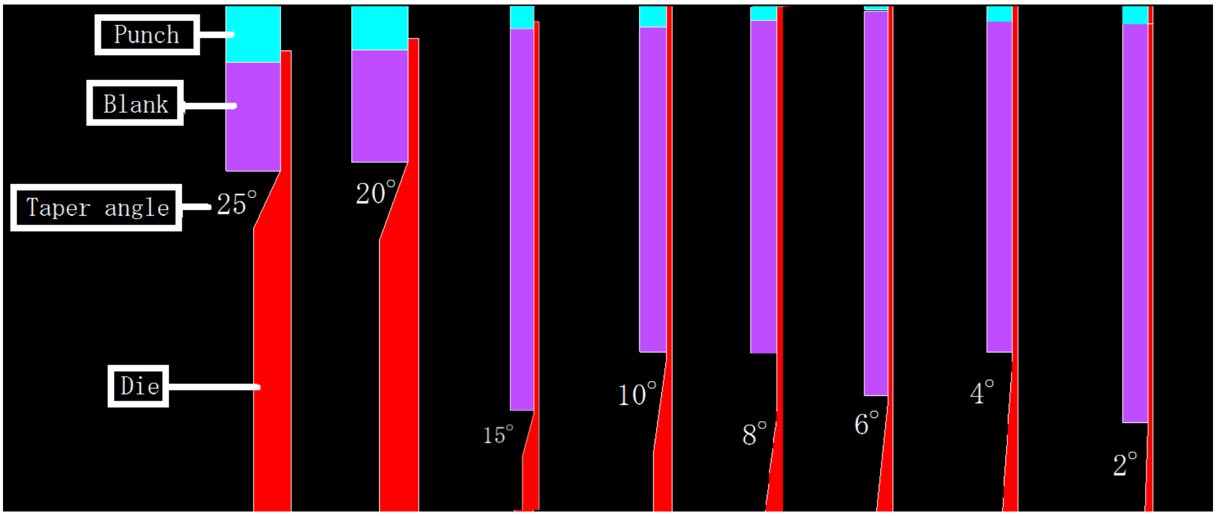


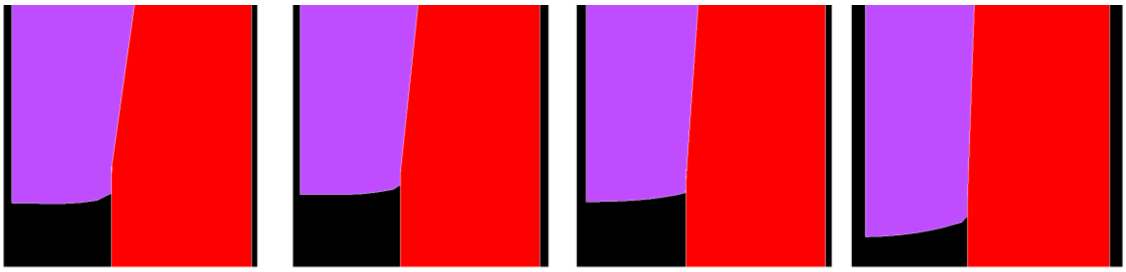
Figure1 Analysis model in a variety of taper angle

3 RESULTS AND DISCUSSION

3.1 Investigation by deformation pattern

Analysis of forward extrusion was conducted to observe the deformation pattern near outlet part. Figure 2 shows difference of deformation pattern between 2° and 25°. This difference shows following two factors. The one case of less than 8°, the center of work piece was flowed out immediately after flowing through the taper section, because it seems that effect of friction is more dominant than more than 10°. The other case of more than 10°, circumstance part of work piece was flowed out, because it seems that effect of material flow is more dominant than less than 8°. From the above, deformation pattern of work piece attribute to friction.

(a) Taper angle 25° Stroke 3.6mm
(b) Taper angle 20° Stroke 4.2mm
(c) Taper angle 15° Stroke 5.7mm
(d)Taper angle 10° Stroke 8.4mm

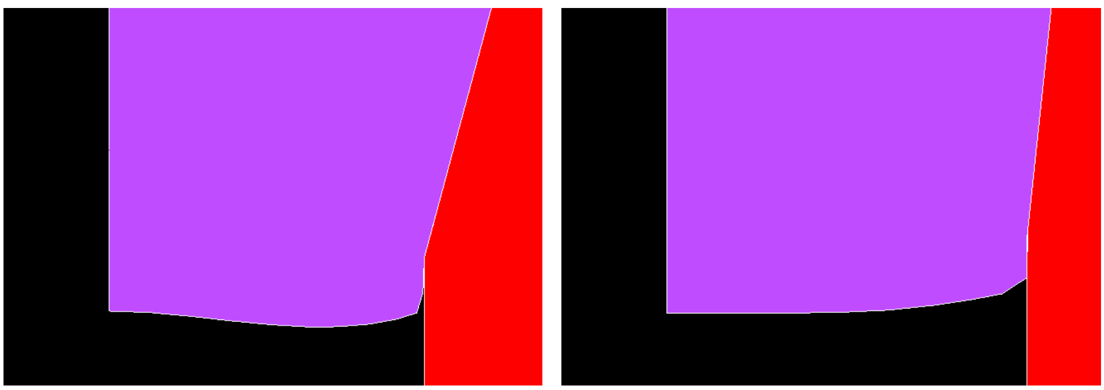


(e) Taper angle 8° Stroke 11.5mm
(f) Taper angle 6° Stroke 14.5mm
(g) Taper angle 4° Stroke 21.6mm
(h) Taper angle 2° Stroke 53.7mm

Figure2 Difference of deformation pattern in different taper angle

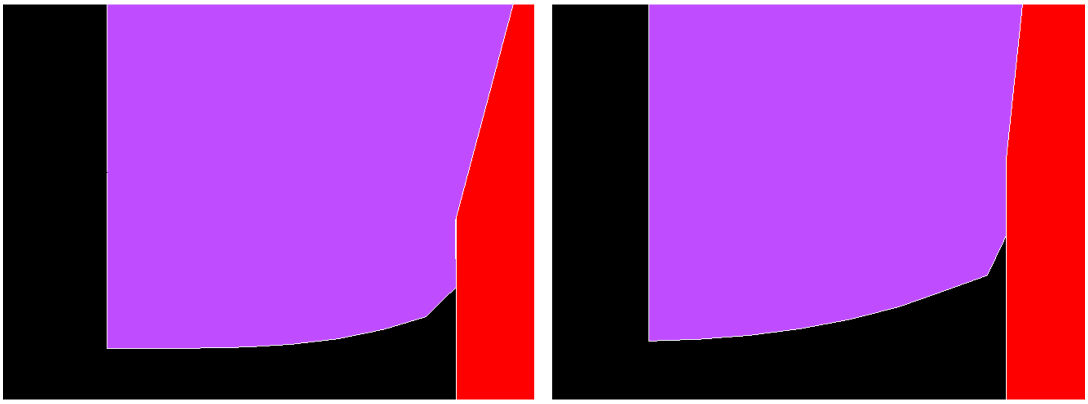
3.2 Effect of deformation pattern and load value by friction

To investigate the effect of friction, analysis was conducted with different friction coefficient value. When both Coulomb friction and shear friction are 0.1, it is expressed as f=0.1. When both Coulomb friction and shear friction are 0.3, it is expressed as f=0.3. Figure 3 shows the comparison between when friction coefficient is 0.1 and when it is 0.3. We compare deformation pattern in case of both 6° and 15° because they have difference of deformation pattern.



(a) Coulomb friction 0.1
Shear friction 0.1
Taper angle 15°

(b) Coulomb friction 0.1
Shear friction 0.1
Taper angle 6°



(c) Coulomb friction 0.3
Shear friction 0.3
Taper angle 15°

(d) Coulomb friction 0.3
Shear friction 0.3
Taper angle 6°

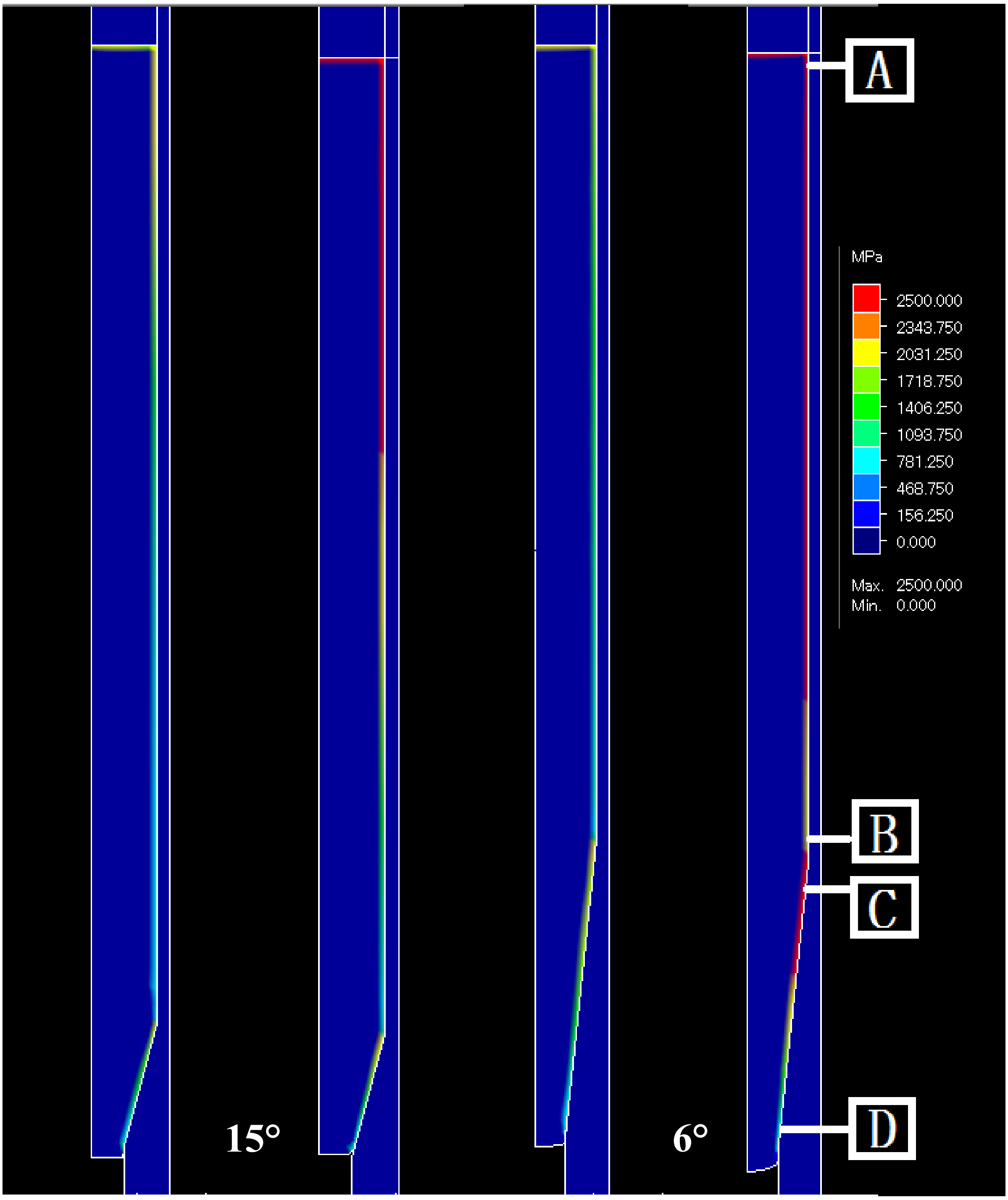
Figure 3 Effect of friction on deformation pattern

Figure 3 shows deformation pattern in case of changing friction coefficient. As a result, the bigger friction coefficient, the bigger center flow amount because it seems that deformation pattern is affected by friction coefficient. From the above, it may be suspected that friction coefficient affect processing load value. Therefore, we investigated contact pressure under the same condition at the time of passing through the taper section. Figure 4 shows contact pressure under the same case. To compare at each location, Table 1 Shows contact pressurein case of 2°, 6° and 15°.

Table 1 Contact pressure occurred between work piece and die

	Contact puressure [MPa]		Contact puressure [MPa]		Contact puressure [MPa]	
	Taper angle 15°		Taper angle 6°		Taper angle 2°	
	f=0.1	f=0.3	f=0.1	f=0.3	f=0.1	f=0.3
A Near the punch	1400	3000	1500	3600	1550	6400
B Just before inflow	700	1200	1000	2200	2000	5200
C Immediately after inflow	1800	2200	2000	3000	3100	6300
D After processing	1000	1100	900	1000	800	900

Figure 4 shows that, there was no difference in contact pressure distribution by difference in taper angle when friction in the case of f=0.1. However, the bigger the friction coefficient, the bigger the contact pressure distribution at the upper of taper. From the above, due to work hardening in the vicinity of the outlet part, the material flow becomes worse. As a result, the extrusion load was increased. Therefore, processing load value required for machining increases. As can be seen from the Table 1, contact pressure is big when the taper angle is small and the frictional coefficient is large. This is because, compression deformation occurs before the material flows into the taper section by hardening in the vicinity of the outlet part



(a) f=0.1 Taper angle 15° (b) f=0.3 Taper angle 15° (c) f=0.1 Taper angle 6° (d) f=0.3 Taper angle 6°

Figure 4 Difference of contact pressure

and friction will occur on the inner wall surface of the die. Therefore, to clarify the causal relation between the contact pressure and the processing load, processing load is shown Figure 5.

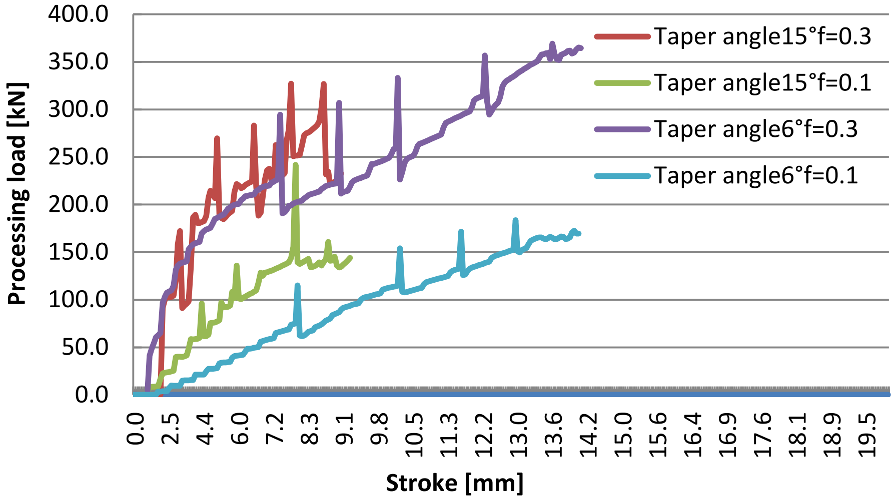


Figure 5 Difference of processing load

In the case of f=0.1, interval in the processing load value between 15 ° and 6 ° is 15 kN. Also, in the case of f=0.3, interval in the processing load value between 15 ° and 6 ° is 80 kN. When the taper angle is 6 ° and friction coefficient is 0.3, the contact pressure is big as compared with the case of 15 °. Therefore, it seems that processing load is increased by influence of friction increasing when taper angle is small. Therefore, as the processing load value vibrates, fatigue fracture punch and die can occur. In addition, we analysed processing load value in the case of 2°. Figure 6 shows processing load value in the case of 2°. Result of analysis, necessary processing load is 220 kN when f=0.1. Also, necessary processing load is 524 kN when f=0.3. The necessary processing load is the biggest when taper angle is 2° in each taper angle. Therefore, there is a possibility of causing die cracking, since the processing load to be used is large.

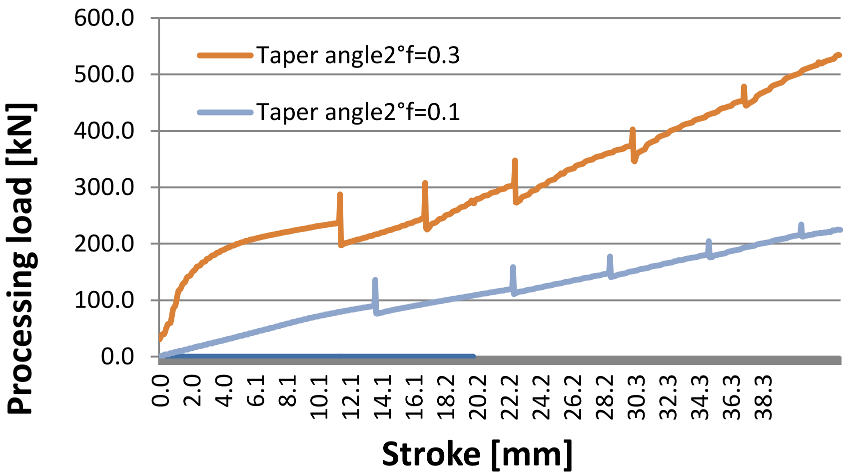
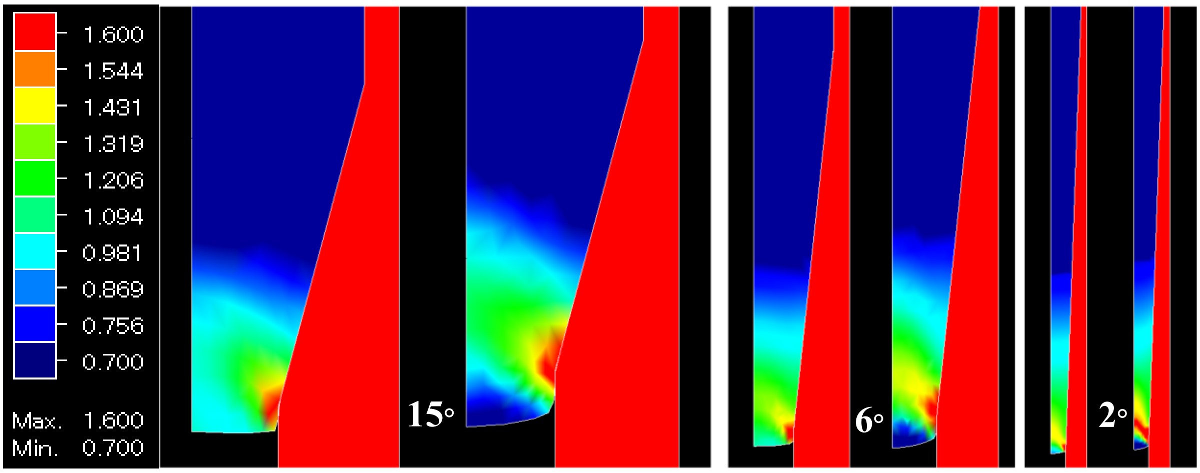


Figure 6 Processing load in the case of 2°

3.3 Investigation by plastic strain

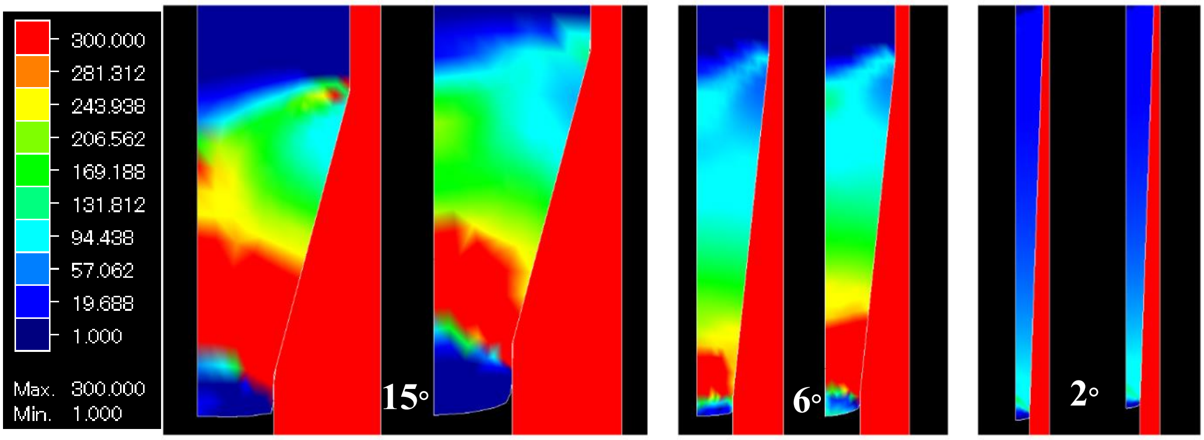
It has been reported that deformation resistance which increases due to work hardening and the work hardening has velocity dependence.[5] In addition, the faster the strain rate, the bigger the work hardening, but deformation resistance becomes smaller. Therefore, the reason why the processing load increases as the taper angle becomes smaller is considered to be in work hardening due to plastic strain. Figure 7 shows results of analysis of plastic strain.



(a) f=0.1 (b) f=0.3 (c) f=0.1 (d) f=0.3 (e)f=0.1 (f)f=0.3
Taper angle 15° Taper angle 6° Taper angle 2°

Figure 7 Difference of plastic strain distribution in friction coefficient

Figure 7 shows plastic strain has occurred in the tapered portion, and deformation resistance is increased by work hardening. It has been reported that the deformation resistance rapidly increases when the plastic strain is bigger than 0.7, but this tendency does not appear when the strain rate is 10^2 s^{-1} or more. [6] Therefore, it is considered that deformation resistance is occurred in the portion where the strain rate is small and plastic strain is big. In order to investigate the extent of work hardening, we analyzed strain rate. Figure 8 shows that when the taper angles are 15 ° and 6 °, the strain rate becomes big around the outlet section. Also, it has been reported that the hardness increases as the strain rate increases during compression processing. It can be seen that when the taper angles are 15 ° and 6 °, the hardness after extrusion is bigger than in the case of 2°. It has been reported that as the strain rate increases, the deformation resistance decreases[6]. the processing load becomes bigger as compared with processing at 15 ° and 6 ° when the taper angle is 2 °. This is due to the effect of friction between inside of the die and the work piece and increase deformation resistance with small strain rate.



(a) f=0.1 (b) f=0.3 Taper angle 15° (c) f=0.1 (d) f=0.3 Taper angle 6° (e) f=0.1 (f) f=0.3 Taper angle 2°

Figure 8 Strain rate in each angle

4 CONCLUSIONS

In forward extrusion processing, we analyzed the taper angle from 25 ° to 2 °. As a result, the smaller the taper angle, the bigger the processing load. Also the bigger friction coefficient, the bigger deformation resistance. For this reason, plastic strain has occurred in the tapered portion, and deformation resistance is increased by work hardening due to this, and friction by contact pressure increases deformation resistance. From the above, processing load causes cracking of the mold due to increase of processing load. It was revealed that processing is difficult when the taper angle is 2 ° or less.

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